§29. Self-Organization of Large-Amplitude Waves and Associated Particle Acceleration

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We have studied the nonlinear evolution of shock waves in a magnetized plasma and the acceleration of positrons, energetic ions, and electrons in those waves with relativistic electromagnetic particle simulations [1-7]. Also, we have investigated the effect of the presence of multiple ion species on the development of current-driven instabilities and energy transport and on the propagation and damping of perpendicular Bernstein waves and magnetosonic waves [8-10].

Here, we describe the results of relativistic particle simulations of positron acceleration by a shock wave propagating obliquely to a magnetic field in an electron-positron-ion plasma [2,3]. After the encounter with a shock wave, some positrons are accelerated along the magnetic field. The acceleration can become plateau owing to the deformation of the wave profile, which arises from the nonstationarity of the wave propagation. After the recovery of the wave profile, however, the acceleration can start again. By the end of the simulation, $\omega_{pe}t$ = 5000, the Lorentz factors of accelerated positrons reach γ ~2000. Further, in this second stage acceleration, we find three different types of particle motions.

Figures 1-3 show time variations of γ for three different acceleration types. Here, γ represents the simulation result, γ_{HUO} is the energy increase calculated by use of the theory of parallel acceleration [2,5], and $W_\perp$ is the work done by perpendicular electric fields. The acceleration is stagnant for $1000<\omega_{pe}t < 2000$. The first type particle (Fig. 1) is accelerated nearly parallel to the magnetic field for $\omega_{pe}t>2000$ as in the early phase ($\omega_{pe}t<1000$); thus, γ and γ_{HUO} have similar profiles. The second type particle (Fig. 2) absorbs energy mainly from perpendicular electric fields in association with large-radius gyromotion; thus, γ and $W_\perp$ are similar. In the third type (Fig. 3), particle orbits resemble curtate cycloids. The energy jumps occur when the particle is reflected by the wave. Theoretical estimates for these three types of acceleration have been given. They quantitatively explain the simulation results.

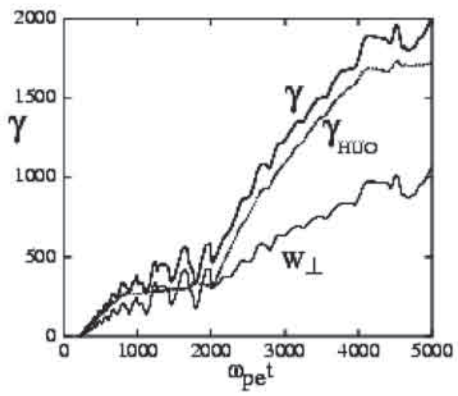

Fig. 1. Time variations of γ, γ_{HUO}, and $W_\perp$ of a positron accelerated nearly parallel to the magnetic field. $W_\perp$ is normalized to m_ec^2.

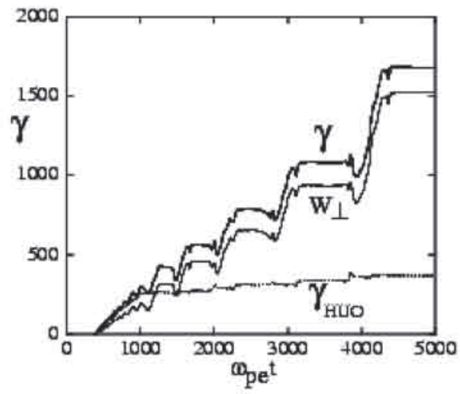

Fig. 2. Time variations of γ, γ_{HUO}, and $W_\perp$ of a positron accelerated by perpendicular electric field in association with large-radius gyromotion.

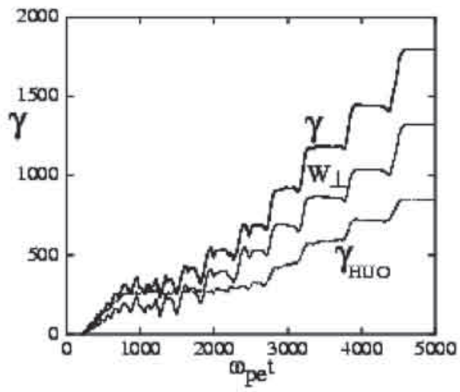

Fig. 3. Time variations of γ, γ_{HUO}, and $W_\perp$ of a positron with an orbit similar to a curtate cycloid.

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